The Application of Sea Level Pressure and Vorticity Fields derived from the University of Washington Planetary Boundary Layer Model in the NOAA Ocean Prediction Center

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Abstract -**The SeaWinds scatterometer onboard the NASA QuikSCAT satellite has been providing forecasters in the Ocean Prediction Center (OPC) with Near-Real Time (NRT) ocean vector winds over large ocean areas since 1999. The OPC forecasters routinely use QuikSCAT winds in their analysis and forecast process to position frontal features, centers of high and low pressure and to determine the category and location of short term wind warning areas. QuikSCAT has also given forecasters the ability to detect hurricane force conditions within extratropical cyclones. Since QuikSCAT has been fully integrated in to OPC operations, OPC forecasters' assessment of the surface wind field over the open oceans is more accurate than ever before. As part of the warning and forecast process, OPC forecasters prepare a manual sea level pressure (SLP) analysis four times daily for both the North Atlantic and North Pacific. These OPC SLP analyses are disseminated directly to ships at sea and are heavily relied upon by the marine community for safe and economic operations. These analyses are also a key element in the forecast process as accurate initial conditions are essential to the production of precise forecasts.**

Although QuikSCAT's impact on the analysis and forecast process has been significant to the short-term wind warning process, this positive impact has not carried over to the analysis of the sea level pressure field over the open oceans. In an effort to improve their SLP analyses, OPC began to run the University of Washington Planetary Boundary Layer (UWPBL) model to derive SLP, surface vorticity and surface wind speed fields using the NRT QuikSCAT winds from NOAA/NESDIS as input. The UWPBL model derived SLP, surface vorticity and surface wind speed fields were made available to OPC forecasters within their N-AWIPS workstations so that they could overlay these products with other observational fields and model guidance. The SLP fields from the UWPBL model were examined daily over a three-month period. The model was found to produce dynamically consistent SLP fields the majority of the time. A comparison of the SLP fields derived from the UWPBL model with the OPC manual surface analyses and the Global Forecast System Model (GFS) surface pressure fields revealed that in most cases the central pressure of the cyclones were not analyzed to be deep enough by either the OPC manual analyses or the GFS model output. There were occasional instances, however where the UPWBL model produced central pressures that were unrealistically low and/or high. This problem was determined to be related to stratification issues and to the method of assimilation of available ship and buoy observations into the model to seed the pressure gradient field.

This paper will present several case studies illustrating the application of UWPBL derived sea level pressure and vorticity by OPC forecasters. Comparisons of OPC manual analyses, numerical model analyses and the UWPBL fields will be shown. The UWPBL model using QuikSCAT winds as input provides very high quality sea level pressure fields associated with intense ocean storms. In particular, the retrieved sea level pressures contain strong pressure gradients in areas of very high winds. This strength of the pressure retrieval system has made it very useful to OPC forecasters in daily operations and as a training tool.

I. Introduction

The OPC is responsible for the issuance of short-term wind warnings for the North Atlantic and North Pacific high seas waters from 35 degrees W to 160 degrees E longitude. As part of the warning and forecast process, OPC forecasters prepare a manual sea level pressure (SLP) analysis at 0000, 0600, 1200, and 1800 UTC for both the North Atlantic and North Pacific each day. OPC SLP analyses are disseminated directly to ships at sea and are heavily relied upon by the marine community for safe and economic operations. These analyses are also a key element in the forecast process as accurate initial conditions are essential to the production of precise forecasts. The SeaWinds scatterometer onboard the NASA QuikSCAT satellite has been providing forecasters in the Ocean Prediction Center (OPC) with Near-Real Time (NRT) ocean vector winds over large ocean areas since 1999. The OPC forecasters routinely use QuikSCAT winds in their analysis and forecast process to position frontal features, centers of high and low pressure and to determine the category and location of short term wind warning areas. QuikSCAT has also given forecasters the ability to detect hurricane force conditions within extratropical cyclones. Since QuikSCAT has been fully integrated in to OPC operations, OPC forecasters' assessment of the surface wind field over the open oceans is more accurate than ever before. .

Although QuikSCAT has had a significant impact on the short-term wind warning process, this positive impact has not carried over to the analysis of the sea level pressure field over

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the open oceans. While QuikSCAT ocean vector winds have greatly reduced the gap in observations of surface wind speed and direction over the open oceans, there still exists a large gap in observations of slp. The University of Washington Planetary Boundary Layer (UWPBL) Model (developed by the PBL group at the University of Washington) uses ocean vector winds from QuikSCAT to calculate various PBL quantities such as slp, surface vorticity, surface wind speed and divergence [1]. In an effort to improve their SLP analyses, OPC conducted a study to evaluate the use of the SLP fields derived from the UWPBL model as an observational source. Forty extratropical cyclones (20 in the Atlantic and 20 in the Pacific) were chosen for this study. A comparison of the SLP fields derived from the UWPBL model with the OPC manual surface analyses and the Global Forecast System Model (GFS) surface pressure fields revealed that in most cases the central pressure of the cyclones were not analyzed to be deep enough by either the OPC manual analyses or the GFS model output. Based on these results, in June 2005, OPC began running the UWPBL model in NRT in a quasi-operational mode. The UWPBL model derived SLP, surface vorticity and surface wind speed fields were made available to OPC forecasters within their N-AWIPS workstations so that they could overlay these products with other observational fields and model guidance. The SLP fields from the UWPBL model were examined daily and over a three-month period the model was found to produce dynamically consistent SLP fields the majority of the time. There were instances, however where low centers were unrealistically low and/or high centers unrealistically high. This problem was determined to be related to stratification issues and the assimilation of available ship and buoy observations into the model to seed the pressure gradient field. To correct the stability problems an SST field and an air temperature field were used as input in place of a constant value. This change resulted in more realistic pressure values. The pressure observation assimilation problem is still under investigation.

The UWPBL model using QuikSCAT winds as input provides very high quality sea level pressure fields associated with intense ocean storms. In particular, the retrieved sea level pressures contain strong pressure gradients in areas of very high winds. This strength of the pressure retrieval system has made it very useful to OPC forecasters in daily operations and as a training tool.

The successful application of the pressure retrieval process at the OPC (using the UWPBL model) is a direct result of the high quality of the input QuikSCAT wind speeds and directions (in all weather conditions), and the ability of QuikSCAT to see entire synoptic scale storm systems in a single continuous swath.

The initial evaluation study is discussed in section II. Section III. contains several case studies illustrating the use of UWPBL derived sea level pressure and vorticity fields in daily OPC operations. Comparisons of OPC manual analyses, numerical model analyses and the UWPBL fields are shown. Concluding remarks are found in section IV.

II. Evaluation Study

A. Background

As part of the analysis and forecast process, OPC forecasters produce a manual surface analysis for the North Atlantic and North Pacific four times daily at 0000, 0600, 1200, and 1800 UTC. The slp field is analyzed in contour intervals of 4 hPa. The current locations of High and Low pressure centers (along with the central pressure), fronts and troughs, and short term wind warning areas are plotted along with the 24 hour forecast position of the High and Low pressure centers. Using the 6hr slp pressure forecast from the GFS model as a first guess, modifications are made using the most recent ship and buoy observations, QuikSCAT ocean vector wind data and satellite imagery.

The ocean vector surface wind data from QuikSCAT has eliminated much of the data gap in observations of wind direction and speed over the oceans. However, a data gap in observations of slp over the ocean areas still existed. By using the NRT MGDR-lite QuikSCAT winds vectors from NOAA/NESDIS as input, the UWPBL model would produce field of slp with the same aerial and temporal extent as the wind field provided by QuikSCAT.

B. Method

To evaluate the usefulness of the UWPBL model as an observational tool (to provide slp data over the oceans), OAB conducted a study using the slp fields derived from the UWPBL model using NRT MGDRLITE QuikSCAT winds from NESDIS as input. Forty extratropical cyclones (20 in the Atlantic, 20 in the Pacific) of various intensities and locations were chosen for evaluation. The UWPBL model was run for each cyclone using the QuikSCAT pass closest in time to the analysis time as input. Ship and buoy observations of sea level pressure that fell within the pass were used to seed the pressure gradient field to produce a surface pressure field. For each case, the UWPBL surface pressure analysis was compared to the corresponding OPC manual surface analysis and GFS model analysis or forecast and the difference in central pressure between UWPBL and OPC (UWPBL – OPC) and UWPBL and GFS (UWPBL – GFS) was computed.

C. Results

In the majority of the cases, the UWPBL produced lower central pressures than either OPC manual analyses or the model generated pressure fields. (Von Ahn et al 2005) Table 1 contains the average difference in central pressure for each ocean.

TABLE1.
AVERAGE DIFFERENCE IN HPA BETWEEN THE CENTRAL PRESSURE FROM UWPBL MODEL AND THE OPC MANUAL ANALYSES AND THE UWPBL MODEL AND THE GFS NUMERICAL GUIDANCE. (FROM VON AHN ET AL. 2005)

	UWPBL- OPC	**UWPBL- GFS**
Atlantic	**-2.7**	**-3.3**
Pacific	**-1.3**	**-2.0**

The larger difference in the Atlantic is due to several cases where the difference in central pressure was significant (greater than 7 hPa). Upon examination of the surface Observations from ships and buoys that were available for these cases, it was evident that the UWPBL model did not "draw" for the observations. The central pressures in these instances were analyzed to be too deep. The reason for this appears to be twofold. The first is related to stratification issues. For 40 studies in the evaluation the model was run using the same constant value for SST and Surface Air temperature. A uniform SST and Surface Air Temperature field and an Air-Sea Temperature difference of 0 resulted in neutral stability condition. The model was rerun using the Real Time Global (rtg) SST field (from the Marine Modeling and Analysis Branch at NCEP) and the 2-meter temperature field from the GFS model as input. The resulting central pressure values were more realistic and in most cases consistent with the observations used to seed the pressure gradient field. The second issue appears to be related to the method used to assimilate the ship and buoy observations into the model. OAB used the time from the QuikSCAT filename to determine the time of the file containing the collocated ship and buoy observations. Since the time in the filename is the time of the first observation in the swath it does not always correspond to the time that the satellite was over the region of interest. Thus the observations used to seed the pressure gradient field could be several hours earlier or later than the QuikSCAT pass time. OAB is in the process of altering the assimilation scheme to correct for this.

Since the model produced dynamically consistent slp fields the majority of the time, OAB began to run the UWPBL model in a quasi-operational mode. The slp, surface wind speed and surface vorticity fields were made available to the forecasters within their N-AWIPS workstations in near-real time. This capability increased the usefulness of the UWPBL as an observational tool by providing the forecasters with the capability to overlay the output fields over other observational fields, model fields, and previous manual analyses.

III. CASE STUDIES.

The second phase of the study involved the evaluation of the performance of the UWPBL model running in quasi-operational mode The following case studies provide excellent examples of how the slp and surface vorticity fields generated by the UWPBL model would be used as an operational tool.

The first case is a cyclone in the North Pacific on 10 January 2005. The numerical guidance from the 0600 UTC GFS model run that was used as a first guess for the indicated a 999 hPa low at 43N, 162E (Fig.1b). There were no ship or buoy observations in the vicinity of the low, however the 0709 UTC QuikSCAT pass showed an area of Hurricane Force (HF) winds to the southwest of the low center (Fig.1d). The strongest winds forecast by the GFS model (not shown) were GALE FORCE. In this situation since there were no surface pressure observations available, the forecaster was hesitant to stray too far from model guidance, even though QuikSCAT winds indicated a significantly stronger low. The forecaster analyzed a 997 hPa low at 42N, 163E on the 0600UTC manual surface analysis (Fig.1a). The slp output from the UWPBL model using the QuikSCAT winds from 0709 UTC as input (Fig. 1d) produced a significantly deeper cyclone (982 hPa) 42N, 164E.). This pressure field was consistent with the SLP observations that were available. The stronger pressure gradient to the south of the low center more accurately represented the HF winds as observed by QuikSCAT. In this situation, the UWPBL SLP analysis would have given the forecaster the confidence to deepen the low, to tighten the pressure gradient and to warn for the hurricane force conditions on the 0600 UTC OPC manual surface analysis

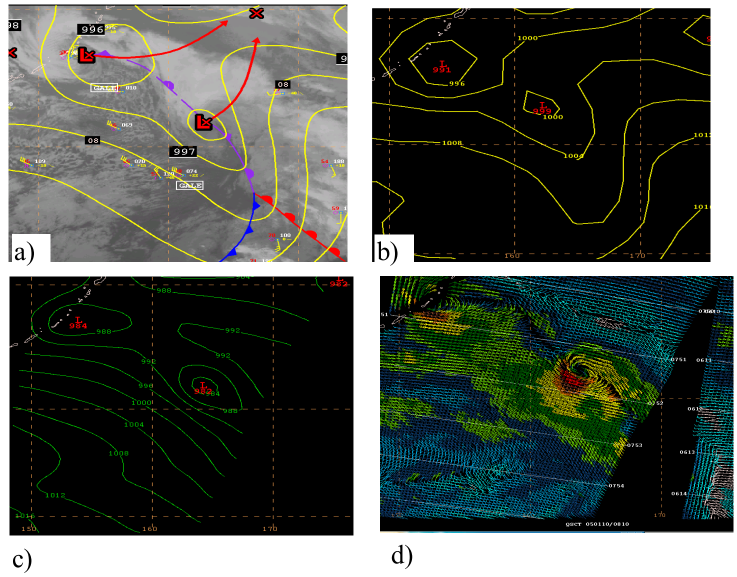


Fig.1: a) OPC manual surface analysis for 0600 UTC 10 January 2005 superimposed over IR satellite image from 0600 UTC 10 January 2005. Surface pressure is drawn with yellow isobars in 4 hPa intervals. The red letter L indicates low centers. b) GFS surface analysis for 0600 UTC 10 January 2005. Surface pressure is drawn with yellow isobars in 4 hPa intervals. Low centers are indicated by a red letter L c) SLP analysis generated by UWPBL model for 0709 UTC 10 January 2005. Surface pressure is drawn with green isobars for 4 hPa intervals. The red letter L indicates low centers. d) QuikSCAT pass from 0709 UTC 10 January 2005. HF winds are shown in red barbs.

The second case involves a low in the North Atlantic on 21 December 2005. The GFS model guidance for 0600UTC depicted a 981 hPa low at 48N, 39W. A ship positioned at 49N, 38W observed a surface pressure or 977 hPa at 0600 UTC. OPC decided to follow model guidance and analyzed a 981 hPa low on the 0600 UTC surface analysis. A 0830 UTC QuikSCAT pass received later in the forecast period indicated an area of 65kt winds to the south west of the low center. The UWPBL model run using the winds from the 0830UTC QuikSCAT pass generated a low with a central pressure of 970 hPa at 49N, 38W. This was supported by a 0800 UTC buoy observation of 973 hPa at 49.5N, 39.5W. GFS model guidance for 1200 UTC placed the low at 51N, 36W with a central pressure of 984 hPa. A ship located at 48.5N, 37W (just to the south west of the low center) reported a surface pressure of 976hPa and 50kt winds. Based on the 0830 UTC QuikSCAT pass and slp field from the UWPBL model the OPC forecaster chose to give more credence to the ship observation and analyzed a deeper 975 hPa low at 49.5N, 36W on the 1200 UTC sfc analysis.

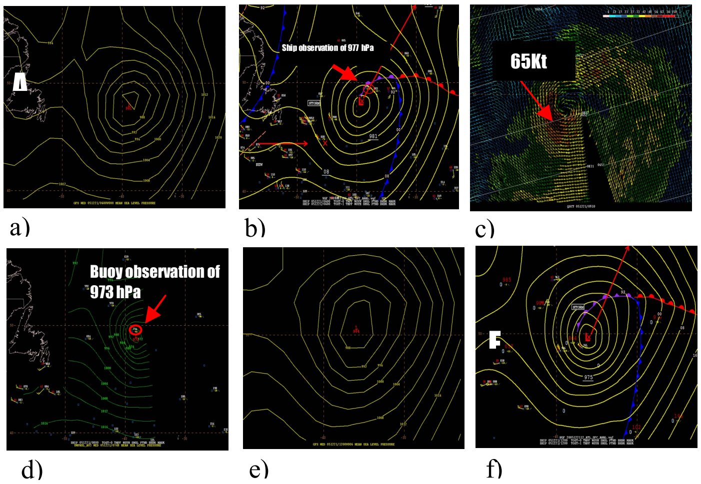


Fig.2: a) GFS surface analysis for 21 December 2005 0600 UTC. Surface pressure is drawn with yellow isobars in 4 hPa intervals. Low centers are indicated by a red letter L. b) OPC manual surface analysis for 0600 UTC 21 December 2005. Surface pressure is drawn with yellow isobars in 4 hPa intervals. The red letter L indicates low centers. Ship observations plotted in standard station plot format. c) QuikSCAT pass from 0830 UTC 21 December 2005. HF winds are shown in red barbs. d) SLP analysis generated by UWPBL model for 0830 UTC 21 December 2005. Surface pressure is drawn with green isobars for 4 hPa intervals. The red letter L indicates low centers. e) Same as a) but for 1200UTC, f) Same as b) but for 1200UTC.

The third case study from 10 February 2006 is an example of how the UWPBL model output can be used not only to determine the intensity of a low but the storm structure as well. The 6 hr forecast from the 1200 UTC run of the GFS model for 060210 1800UTC indicated a closed low with a central pressure of 985 hPa at 42N, 159W.

With no ship or buoy observations in the vicinity of the low, the OPC forecaster followed model guidance and also analyzed a 985 Pa low at 42N, 159W on the 1800UTC manual surface analysis. The QuikSCAT pass from 1630UTC did not show any evidence of a closed circulation in the vicinity of 42N, 160 W. However, the shift in wind direction associated with the frontal zone showed up clearly on the QuikSCAT pass. Examination of the GOES IR satellite loop (not shown) for the period between 1200 and 1800UTC did not indicate a closed circulation either.

The slp analysis derived from the UWPBL model using the 1630 UTC QuikSCAT pass clearly indicated an open low in the vicinity of 42N, 162W. A plot of the surface vorticity field also identifies the location of the surface front.

This is a situation where the GFS model guidance was too rigorous in the development of the low pressure system and the UWPBL output was able to correctly depict the storm structure.

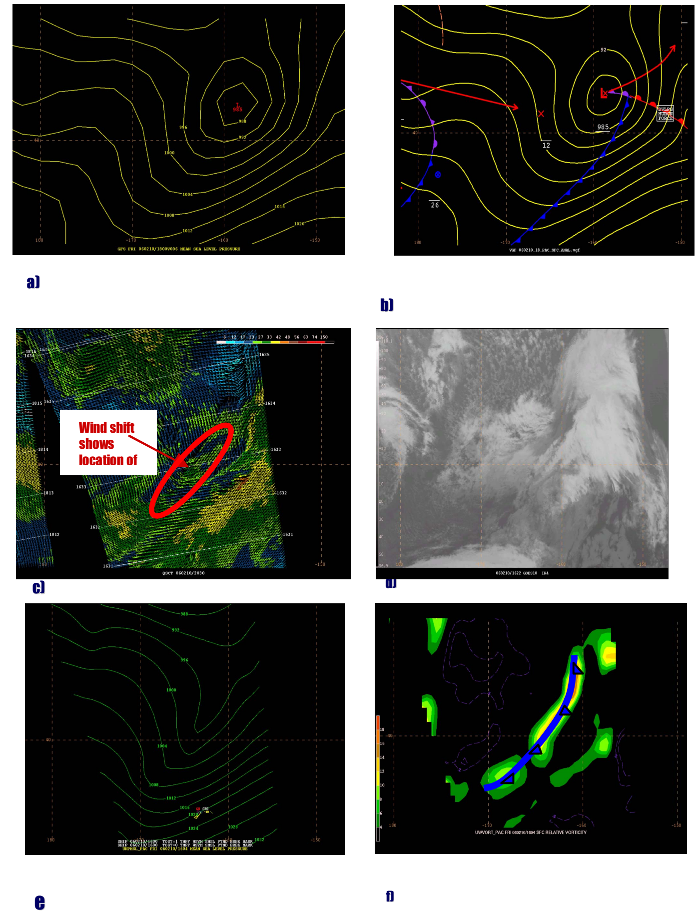


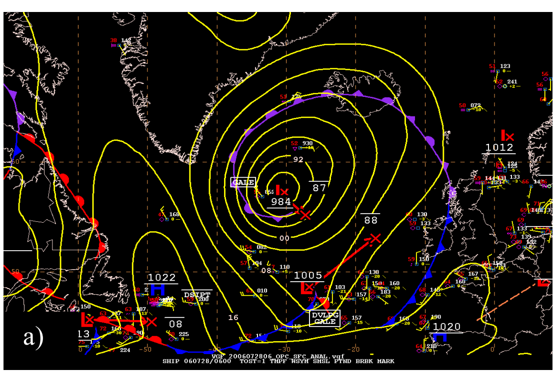
Fig. 3 a) The 6 hr forecast of slp from the 1200 UTC run of the GFS model for 060210 1800UTC. Surface pressure is drawn with yellow isobars in 4 hPa intervals. A red letter L indicates low centers. b) The OPC manual surface analysis for 1800 UTC 10 February 2006. Surface pressure is drawn with yellow isobars in 4 hPa intervals. The red letter L indicates low centers. c) QuikSCAT pass from 1630 UTC 10 February 2006. d) GOES IR satellite image from 1622 UTC 10 February 2006 e) SLP analysis generated by UWPBL model using the 1630 UTC 10 February 2006 QuikSCAT winds as input. Surface pressure is drawn with green isobars for 4 hPa intervals. F) Surface Vorticity generated by the UWPBL model using the 1630 UTC 10 February 2006 QuikSCAT winds as input. The cold front is depicted with the standard cold front symbol.

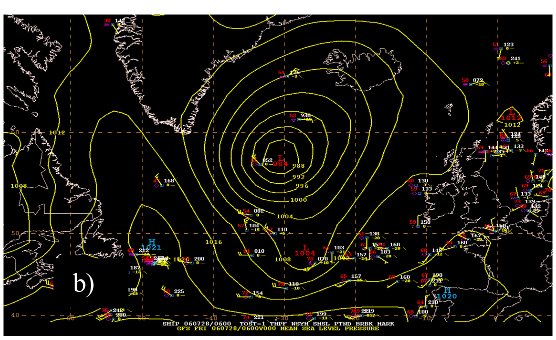
IV. NRT OPERATIONAL USE

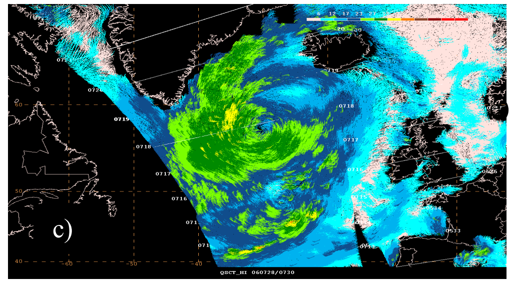
The UWPBL model has been running in NRT in a quasi-operational mode in OPC since June 2005. To be fully incorporated into the operations at OPC an observational tool must meet certain requirements. The data must be dynamically consistent and be available in a timely manner within the forecasters workstations. Optimally the data should be able to be overlaid over other observation fields. Overall the UWPBL slp and vorticity fields have met these criteria and the forecasters have begun to use these fields as an observational tool in their daily forecast production process.

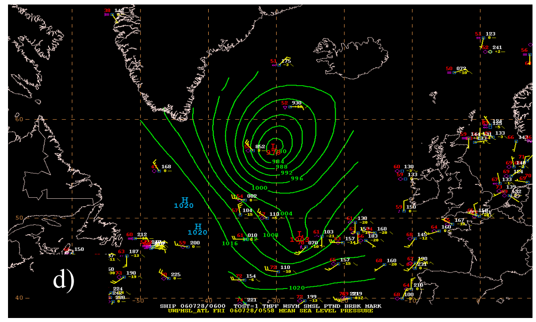
Below is an example of how an OPC forecaster used the slp analysis from the UWPBL in preparation of the 1200UTC manual surface analysis for 28 July 2006. The OPC manual sfc analysis from 0600UTC depicted a 984hPa low to the south east of Greenland at 57.4N, 38.5W (Fig.4a). The 6hr forecast from the 0600UTC (VT 1200UTC) run of the GFS model (Fig. 4b) was used as a first guess field for the 1200UTC manual surface analysis. The GFS analyzed the low at 56.5N, 29.3W with a central pressure of 986hPa. Although there were a few ship observations within the area of the low at 1200UTC, the closest observation was located 120nm from the low center. The forecaster had access to an earlier QuikSCAT pass from 0718UTC (Fig.4c) as well as the slp analysis generated from the UWPBL model using the 0718UTC QuikSCAT winds as input (Fig 4d). To determine how well the 0600UTC GFS model guidance analyzed the synoptic situation the forecaster compared 0600UTC ship observations with the 0600UTC GFS slp analysis and the 0718 UTC UWPBL slp analysis. This comparison revealed that the UWPBL slp analysis was much closer to the actual 0600UTC data than the GFS.

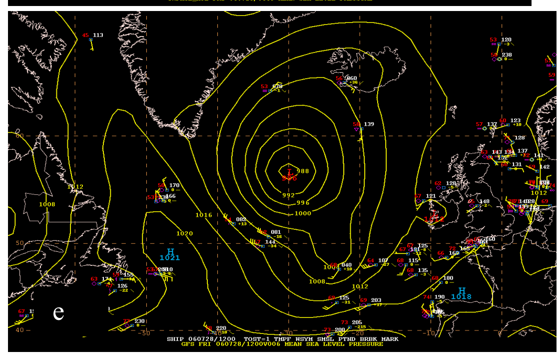
The UWPBL analyzed the low 6hPa lower than the GFS. (978hPa low at 57.5N, 30.2W; 984hPa at 56.4N, 29.1W.) Since the cyclone was no longer intensifying, the forecaster believed that the UWPBL central pressure of 978hPa was too deep. However, since QuikSCAT did observe a small area of 35kt winds the forecaster believed that the GFS central pressure of 984hPA was too weak. Based on the conclusions from these comparisons within the 0600 UTC time frame the forecaster made the decision to analyze the low on the 1200UTC OPC Manual analysis at 56.9N, 29.9W with a central pressure of 983hPa. This was 3hPa lower than the 986hPa central pressure indicated on the 1200UTC GFS model guidance). This case provides an excellent example of how the UWPBL can be used to determine the central pressure of a low when there are no ship or buoy observations in the immediate vicinity of the low center.











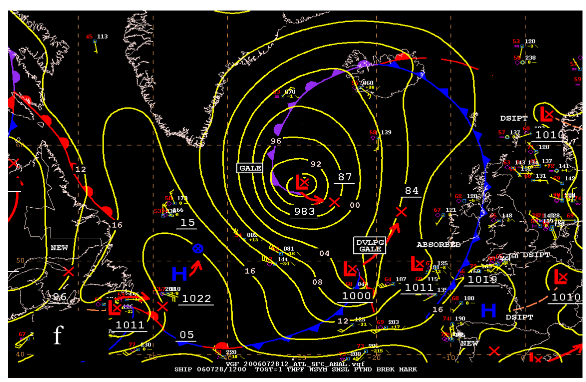


Figure 4: a) The OPC manual surface analysis for 0600 UTC 28 July 2006 Surface pressure is drawn with yellow isobars in 4 hPa intervals. The red letter L indicates low centers b) The 6 hr forecast of slp from the 1600 UTC run of the GFS model for 28 July 2006 1200UTC. Surface pressure is drawn with yellow isobars in 4 hPa intervals. Low centers are indicated by a red letter L c) QuikSCAT pass from 0718 UTC 28 July 2006 d) SLP analysis generated by UWPBL model using the 0718 UTC 28 July 2006 QuikSCAT winds as input. Surface pressure is drawn with green isobars for 4 hPa intervals. e) The GFS surface analysis from the 0600UTC run of the GFS model valid 0600UTC 28 July 2006. f) Same as a) but for 1200UTC.

IV SUMMARY AND CONCLUSIONS

The inclusion of QuikSCAT winds in the OPC has indeed improved the analysis and warning process. The issuance of short-term wind warnings increased by 10% as a direct result of using QuikSCAT wind observations [2]. Forecasters can now assess wind conditions over the open oceans more accurately than ever before. However, the accurate representation of the surface pressure field still remains a problem. With only sparse surface observations of sea level pressure from ships and buoys forecasters are often hesitant to stray too far from the model guidance in analyzing the surface pressure field. The UWPBL was originally developed to produce a sea level pressure field using QuikSCAT level 2B wind as input. Although this model was valuable for examining past cases, it was of no use operationally in NRT. With help from the PBL group at the University of Washington, the OPC adapted the model to use the near real time MDR Lite QuikSCAT data as input so that the model could be run operationally. The forecasters could then use the resulting sea level pressure analyses generated by the model as an additional observational tool for preparation of their manual surface analyses.

For an observational tool to be incorporated into the operations at OPC it must meet certain requirements. It must be available in a timely manner right at the forecasters workstations. Optimally the data should be able to be overlaid over other parameters for ease of comparison. The resulting output must be realistic and meteorologically correct. Overall, the UWPBL model has met these criteria. The output from the model has been converted to GEMPAK for display on the NAWIPS workstations. The model is available in a timely manner and can be used, along with QuikSCAT and any ship and buoy observations to analyze the surface pressure field at a given time. Overall, the performance of the model was encouraging .The model was reliably able to produce dynamically consistent fields of surface pressure. There were a few situations, however, where the resulting pressures were considered to be too deep. The reason for this appears to be related to the assimilation of the surface pressure observations into the model. This must be evaluated before the model can become fully operational.

ACKNOWLEDGMENT

Much thanks to Jerome Patoux, Robert Brown and Ralph Foster of the University of Washington for the development of the UWPBL Model, for their help in adapting the model for implementation in NRT within the OPC and in troubleshooting once the model was running in a quasi-operational mode. Much appreciation also to Curt Janota of the Ocean Applications Branch of OPC and Scott Jacobs of NCEP for their assistance in creating the scripts needed to run the UWPBL model and to display the output in the NAWIPS workstations.

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